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(54) **DIFFUSION SOURCES FROM LIQUID PRECURSORS**

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(52) **U.S. Cl.**
USPC **438/522**; 438/537; 438/542; 438/563; 257/E21.491

(58) **Field of Classification Search**
USPC 438/522, 537, 542, 563; 257/E21.491
See application file for complete search history.

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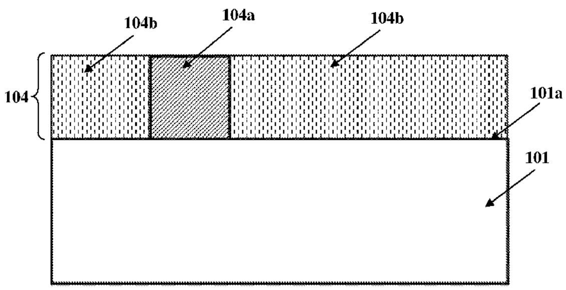
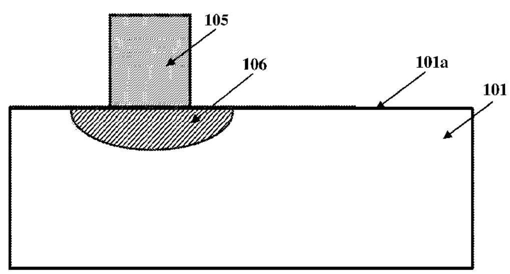
Primary Examiner — Thanhha Pham

(57) **ABSTRACT**

Methods for selectively diffusing dopants into a substrate wafer are provided. A liquid precursor is doped with dopants. The liquid precursor is selected from a group comprising monomers, polymers, and oligomers of silicon and hydrogen. The doped liquid precursor is deposited on a surface of the substrate wafer to create a doped film. The doped film is heated on the substrate wafer for diffusing the dopants from the doped film into the substrate wafer at different diffusion rates to create a heavily diffused region and a lightly diffused region in the substrate wafer. The method disclosed herein further comprises selective curing of the doped film on the surface of the substrate wafer. The selectively cured doped film acts as a diffusion source for selectively diffusing the dopants into the substrate wafer.

20 Claims, 4 Drawing Sheets





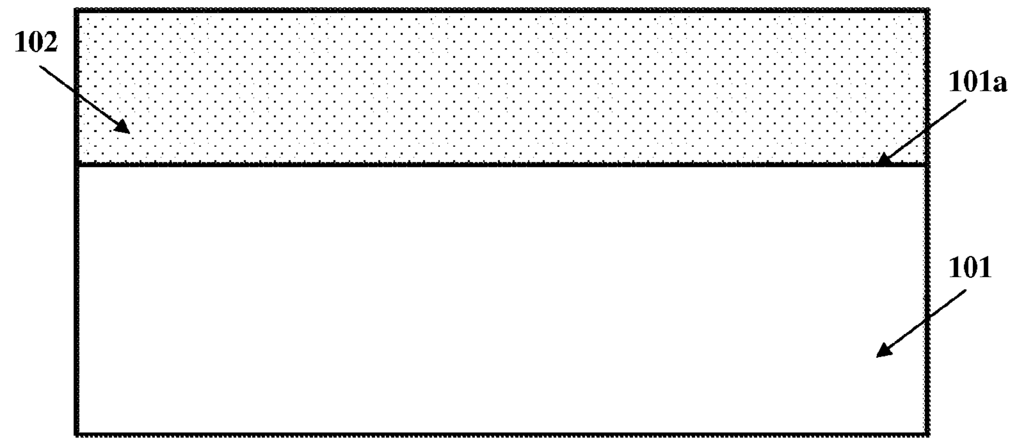


FIG. 1

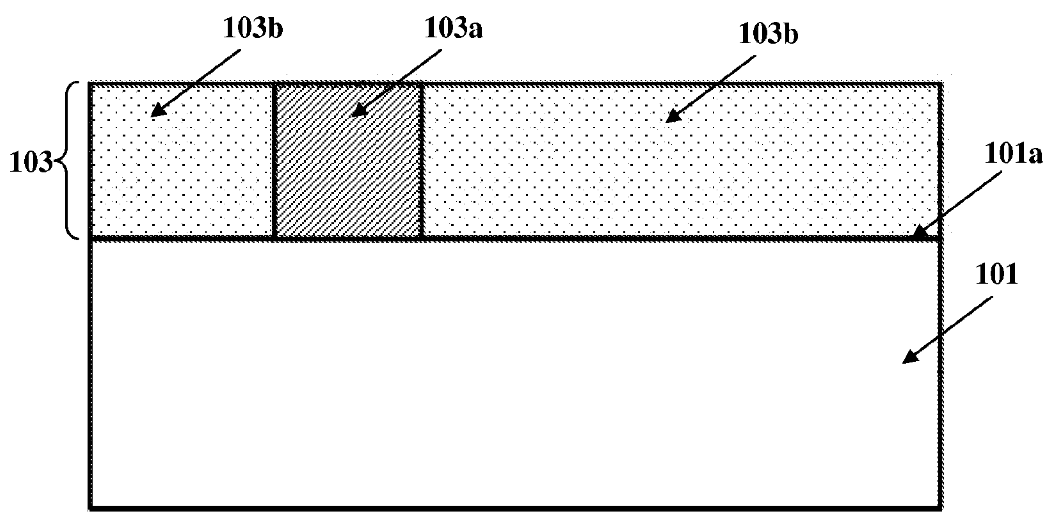


FIG. 2

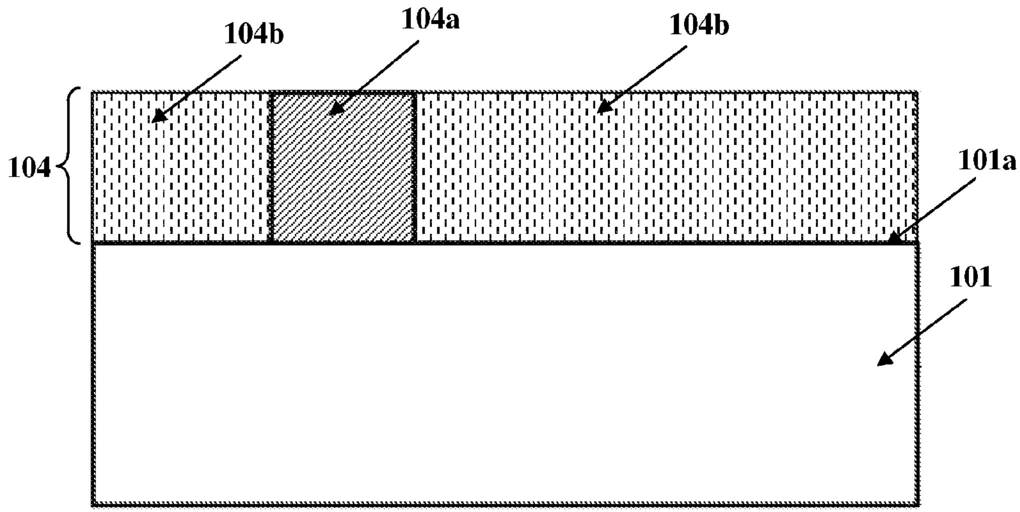


FIG. 3

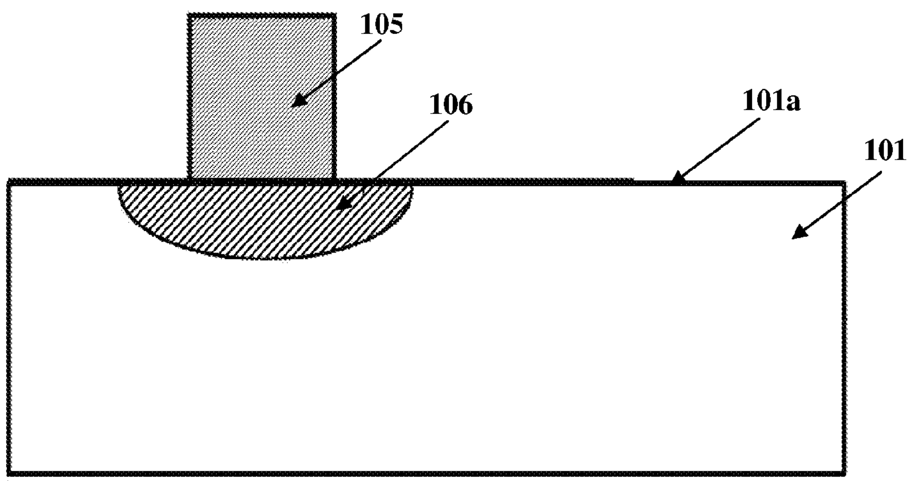


FIG. 4

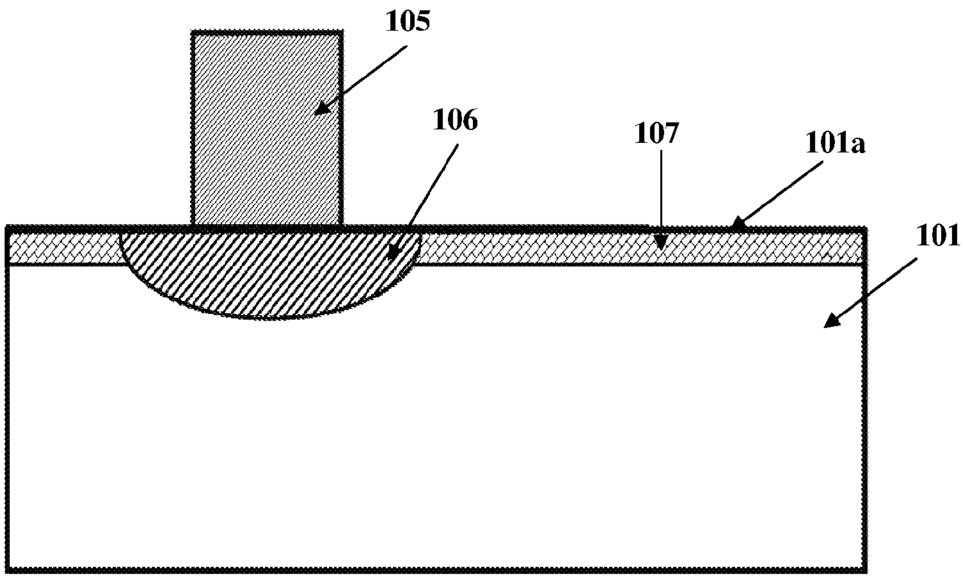


FIG. 5

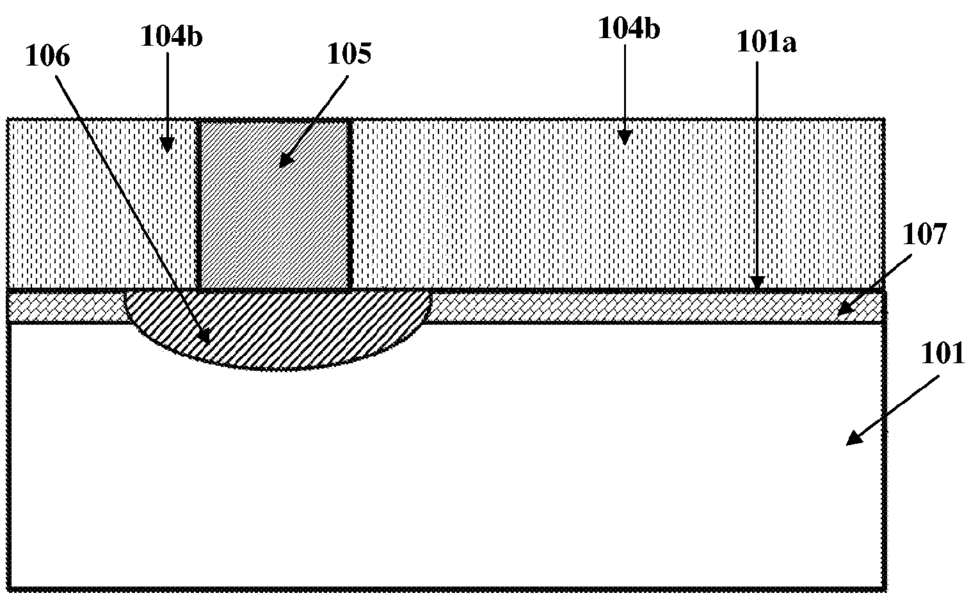


FIG. 6

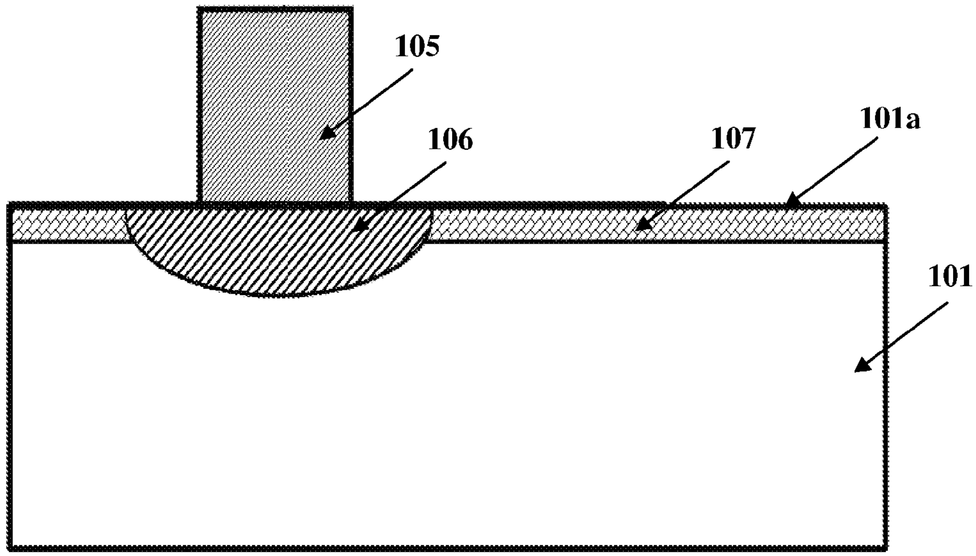


FIG. 7

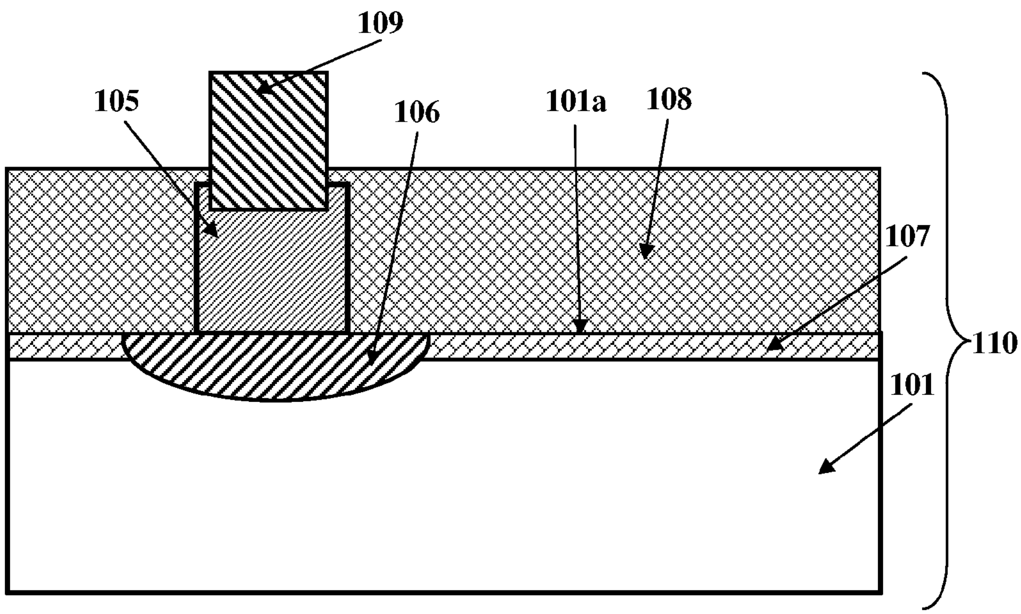


FIG. 8

DIFFUSION SOURCES FROM LIQUID PRECURSORS

BACKGROUND

The method disclosed herein, in general, relates to a process for doping the surface of a solar cell. More particularly, the method disclosed herein relates to a use of a doped film on the surface of the solar cell as a diffusion source.

Typical solar cells are made on p-type silicon wafers with n-type diffusion on a front surface to form a p-n junction. The diffused region is called an emitter, and is usually formed by phosphorus diffusion. The emitter is doped heavily in order to form one or more metal contacts as well as to obtain a low sheet resistance. Silver paste is typically used to provide a metal contact. The silver paste penetrates into the emitter when the silicon wafer is heat treated. Doping of the emitter region needs to be thick to contain the silver within the emitter region and not allow the silver to penetrate into a depletion region or a p-type region. The practical requirements of the heavy phosphorous doping in the emitter region suffer from drawbacks, for example, high surface recombination, high emitter dark current, poor lifetime of the emitter region, and poor spectral response for light absorbed in or near the emitter. Typical solar cells produced in this manner have efficiencies of about fourteen percent.

Hence, there is a long felt need for selective heavy doping of the emitter region under the metal contacts to obtain low contact resistance for the metal and to repel minority carriers from the metal contacts. There is also a need for selective light doping on the rest of the emitter region to achieve low surface recombination, low emitter dark current, higher lifetime of the emitter region, and an improved spectral response for light absorbed in the emitter region. There is this need for dual doping of a silicon wafer for increasing the efficiency of the silicon solar cells. There is also a need for selective heavy doping to form high-low junctions on the back of the semiconductor device, also referred to as back surface fields, or back contact regions on silicon solar cells.

SUMMARY OF THE INVENTION

This summary is provided to introduce a selection of concepts in a simplified form that are further described in the detailed description of the invention. This summary is not intended to identify key or essential inventive concepts of the claimed subject matter, nor is it intended for determining the scope of the claimed subject matter.

The methods disclosed herein address the above stated need for dual doping of a substrate wafer for increasing the efficiency of a solar cell. The dual doping comprises selective heavy doping of an emitter region under metal or metal contacts and selective light doping on the rest of the emitter region. The selective heavy doping of the emitter region under the metal or metal contacts produces a low contact resistance for the metal and repels minority carriers from the metal contacts. The selective light doping on the rest of the emitter region achieves low surface recombination, low emitter dark current, higher lifetime of the emitter region, and an improved spectral response for the light absorbed in the emitter region. The methods disclosed herein also enable selective heavy doping on the substrate wafer.

A method for selectively diffusing dopants into a substrate wafer is provided herein. In the method disclosed herein, a liquid precursor is doped with dopants. The dopants are, for example, p-type impurities or n-type impurities. The liquid precursor is selected from a group comprising monomers, polymers, and oligomers of silicon and hydrogen. The liquid precursor is, for example, one or more of a silane, an oligosilane, and a polysilane, with one or more of linear, branched and particulate structures. The doped liquid precursor is deposited on a surface of the substrate wafer to create a doped film on the surface of the substrate wafer. The deposition of the doped liquid precursor is performed, for example, by one or more of ink-jet printing, screen printing, condensing, pneumatic spraying, ultrasonic spraying, electrospraying, spraying by liquid ejection from an orifice, spraying by direct injection of droplets of the doped liquid precursor impinging on the substrate wafer, spin coating, roller coating, bar coating, curtain coating, dip coating, bar coating, etc.

The doped film is heated on the substrate wafer. The heating of the doped film diffuses the dopants from the doped film into the substrate wafer. Regions of the doped film can be oxidized and used as a diffusion source. Oxidized and non-oxidized regions of the doped film can be used simultaneously as diffusion sources to obtain different sheet resistances. Diffusion of the dopants from the doped film into the substrate wafer comprises simultaneous creation of heavily diffused regions and lightly diffused regions in the substrate wafer based on different diffusion rates. In an embodiment, a lightly diffused region is created in the substrate wafer prior to or after the deposition of the doped liquid precursor.

In an embodiment, the doped liquid precursor is selectively deposited on the surface of the substrate wafer for creating patterns of the doped film on the surface of the substrate wafer, thereby creating a patterned diffusion source on the surface of the substrate wafer. The created patterns of the doped film on the surface of the substrate wafer enable selective diffusion of the dopants into the substrate wafer after the heating of the doped film. Therefore, the liquid precursor may be deposited on selected areas or on the full area of the substrate wafer.

In another embodiment, the doped film is selectively cured on the surface of the substrate wafer. The selectively cured doped film acts as a selected area diffusion source for selectively diffusing the dopants into the substrate wafer. The doped film is selectively cured, for example, by patterned irradiation. The selectively cured doped film is heated to diffuse the dopants from the selectively cured doped film into the substrate wafer. On heating, the selectively cured doped film on the substrate wafer is converted into silicon compounds, for example, silicon polymer, amorphous silicon, polycrystalline silicon, or a mixture of these phases. In another embodiment, the selectively cured doped film is selectively oxidized on the surface of the substrate wafer. The selectively oxidized doped film is heated on the substrate wafer for selectively diffusing the dopants from the selectively oxidized doped film into the substrate wafer.

In another embodiment, the doped film is selectively cured on the surface of the substrate wafer to create cured regions and uncured regions of the doped film on the surface of the substrate wafer. The uncured regions on the surface of the substrate wafer are oxidized to obtain non-oxidized cured regions and oxidized uncured regions of the doped film on the surface of the substrate wafer. The non-oxidized cured regions and the oxidized uncured regions of the doped film are then heated. The dopants diffuse from the non-oxidized cured regions and the oxidized uncured regions of the doped film into the substrate wafer at different diffusion rates to produce differentiated sheet resistances on the surface of the substrate wafer. In an embodiment, the oxidized uncured regions of the doped film are etched from the surface of the substrate wafer, which removes the dopants and prevents diffusion from the oxidized uncured regions.

Disclosed herein is also a use of a doped film as a diffusion source for selectively diffusing dopants into a substrate wafer. The doped film is created by depositing a doped liquid precursor on a surface of the substrate wafer. The doped film is selectively cured on the surface of the substrate wafer and heated for selectively diffusing the dopants from the doped film into selective areas of the substrate wafer where metal contacts are intended to be deposited.

Disclosed herein is also a method for manufacturing a solar cell. A liquid precursor doped with dopants is deposited on a surface of a substrate wafer to create a doped film on the surface of the substrate wafer. The doped film is selectively cured on the surface of the substrate wafer to create cured regions and uncured regions of the doped film. The uncured regions of the doped film are oxidized and etched from the surface of the substrate wafer. The cured regions of the doped film are heated on the surface of the substrate wafer for diffusing the dopants into the substrate wafer to create a heavily diffused region in the substrate wafer. A secondary light diffusion is performed to obtain a low sheet resistance emitter. A silicon nitride layer is deposited on the substrate wafer. A metal contact, for example, a silver paste is deposited on the deposited silicon nitride layer aligned to the region where the doped polysilane film is deposited. During heating, the metal contact penetrates the silicon nitride layer to contact the heavily diffused region, thereby manufacturing the solar cell. The created heavily diffused region and the lightly diffused region define one or more diffused emitter regions on the surface of the substrate wafer.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing summary, as well as the following detailed description of the invention, is better understood when read in conjunction with the appended drawings. For the purpose of illustrating the invention, exemplary constructions of the invention are shown in the drawings. However, the invention is not limited to the specific components and methods disclosed herein.

FIG. **1** exemplarily illustrates a doped liquid precursor deposited on a surface of a substrate wafer to create a doped film.

FIG. **2** exemplarily illustrates a selectively cured doped polysilane film on the surface of the substrate wafer.

FIG. **3** exemplarily illustrates a selectively oxidized doped polysilane film on the surface of the substrate wafer.

FIG. **4** exemplarily illustrates diffusion of dopants into the substrate wafer and formation of a crystallized polysilane film.

FIG. **5** exemplarily illustrates a substrate wafer comprising a lightly diffused region created by performing a second light diffusion step for making a continuous emitter.

FIG. **6** exemplarily illustrates use of a non-oxidized cured region and oxidized uncured regions of the selectively oxidized doped polysilane film as simultaneous diffusion sources.

FIG. **7** exemplarily illustrates a substrate wafer after simultaneous diffusion from a non-oxidized cured region and oxidized uncured regions of the selectively oxidized doped polysilane film, with the oxidized uncured regions removed after the diffusion process.

FIG. **8** exemplarily illustrates a solar cell structure manufactured using the method disclosed herein.

DETAILED DESCRIPTION OF THE INVENTION

Disclosed herein is a method for selectively diffusing dopants into a substrate wafer. In the method disclosed herein, a liquid precursor is doped with dopants. The doped liquid precursor is deposited on a surface of the substrate wafer to create a doped film on the surface of the substrate wafer. The doped film is then heated on the substrate wafer to diffuse the dopants from the doped film into the substrate wafer. In an embodiment, a lightly diffused region is created in the substrate wafer prior to the deposition of the doped liquid precursor. In another embodiment, a lightly diffused region is created in the substrate wafer after the deposition of the doped liquid precursor and the heavy dopant diffusion step. In another embodiment, oxidized and non-oxidized regions of the doped film are used as simultaneous diffusion sources to create two different sheet resistances.

In an embodiment, the doped film is selectively cured on the surface of the substrate wafer. Curing of the doped film is performed, for example, using ultraviolet (UV) radiation. The selectively cured doped film acts as a diffusion source for selectively diffusing the dopants into the substrate wafer.

In another embodiment, the uncured regions of the selectively cured doped film are oxidized on the surface of the substrate wafer. Oxidizing the selectively cured doped film refers to exposing the selectively cured doped film to oxygen or moisture. The selectively oxidized doped film on the substrate wafer is then heated for selectively diffusing the dopants from the selectively oxidized doped film into the substrate wafer.

In an embodiment, the doped liquid precursor is selectively deposited on the surface of the substrate wafer for creating patterns of the doped film on the surface of the substrate wafer. The created patterns of the doped film on the surface of the substrate wafer enable selective diffusion of the dopants into the substrate wafer after heating the doped film. As used herein, the term "selective diffusion" of the dopants into the substrate wafer refers to the diffusion of the dopants in selective regions of the substrate wafer at different diffusion rates.

In another embodiment, the doped film is selectively cured on the surface of the substrate wafer to create cured regions and uncured regions of the doped film on the surface of the substrate wafer. The cured regions are very stable, while the uncured regions of the doped film can be oxidized to create non-oxidized cured regions and oxidized uncured regions of the doped film on the surface of the substrate wafer. The non-oxidized cured regions and the oxidized uncured regions of the doped film are then heated. The dopants diffuse from the non-oxidized cured regions and the oxidized uncured regions of the doped film into the substrate wafer at different diffusion rates after heating to produce differentiated sheet resistances on the surface of the substrate wafer. In an embodiment, the oxidized uncured regions of the doped film are etched from the surface of the substrate wafer before a diffusion annealing process, which removes the dopants and prevents diffusion of the dopants from the oxidized uncured regions into the substrate wafer.

FIG. **1** exemplarily illustrates a doped liquid precursor deposited on a surface **101***a* of a substrate wafer **101** to create a doped film **102**. Where the liquid precursor is a polysilane, the doped polysilane liquid precursor deposited on the surface **101***a* of the substrate wafer **101** creates a doped polysilane film **102**. A doped liquid precursor, for example, a doped polysilane liquid precursor after deposition on the surface **101***a* of the substrate wafer **101** is hereafter referred to as a "doped polysilane film" and is no longer a precursor. The substrate wafer **101** is, for example, a silicon wafer. A method for selectively diffusing dopants into the substrate wafer **101** is provided herein. In the method disclosed herein, a liquid precursor is doped with dopants. The liquid precursor is selected from a group comprising monomers, polymers, and oligomers of silicon and hydrogen. The liquid precursor is, for example, a silane, an oligosilane and a polysilane, with linear, branched and particulate structures. The liquid precursors utilized herein comprise, for example, cyclic silanes such as cyclohexasilane, cyclopentasilane, and cycloheptasilane. Oligomers and polymers derived from the above mentioned silanes can also be used. Silanes comprising halogen, for example, chlorine may also be used. The liquid precursors are doped with dopants, for example, phosphorus, boron, etc. The dopants are, for example, p-type impurities or n-type impurities.

Liquid precursors, for example, polysilanes are liquid at room temperature, and are photosensitive. For purposes of illustration, the detailed description refers to a polysilane film **102**; however the scope of the methods disclosed herein is not limited to the polysilane film **102** but may be extended to include films of multiple compositions of silicon based liquid precursors such as silanes, oligosilanes, etc. As polysilanes are liquid at room temperature, the deposition of the polysilane film **102** is performed, for example, by one or more of ink-jet printing, screen printing, condensing, pneumatic spraying, ultrasonic spraying, electrospraying, spraying by liquid ejection from an orifice, spraying by direct injection of droplets of the doped liquid precursor impinging on the substrate wafer **101**, spin coating, roller coating, bar coating, curtain coating, dip coating, bar coating, etc.

The doped polysilane film **102** deposited on the surface **101***a* of the substrate wafer **101** is selectively cured, for example, by heat, light or a radiation process to diffuse dopants into the substrate wafer **101** below to selectively diffuse the dopants into the substrate wafer **101**. FIG. **2** exemplarily illustrates a selectively cured doped polysilane film **103** on the surface **101***a* of the substrate wafer **101**. The deposited doped polysilane film **102** is selectively cured on the surface **101***a* of the substrate wafer **101**, for example, by patterned illumination with ultraviolet light or laser on the polysilane film **102** to, for example, a more stable polymer, an amorphous silicon, etc. The selectively cured doped polysilane film **103** comprises cured regions **103***a* and uncured regions **103***b*.

The deposited doped polysilane film **102** is cured by heat, ultraviolet (UV) light or irradiation. In an embodiment, the deposited doped polysilane film **102** is selectively cured by patterned irradiation using, for example, ultraviolet radiation. The exposure to ultraviolet (UV) light and/or heating of the polysilane film **102** can be restricted to local areas on the polysilane film **102** by using, for example, shadow masks as in lithography, lasers, etc. The polysilane films **102** are pyrophoric due to their high reactivity with oxygen and moisture. The photosensitive and heat sensitive properties of the liquid precursors allow the polysilane film **102** to be patterned and manipulated. During curing, the chemical bonds, for example the silicon-silicon bonds and silicon-hydrogen bonds in the liquid precursors' cross-link, a conversion resulting in a higher molecular weight polysilane polymer or amorphous silicon. After curing, the higher molecular weight polysilane polymer film is stable in air.

FIG. **3** exemplarily illustrates a selectively oxidized doped polysilane film **104** on the surface **101***a* of the substrate wafer **101**. The selectively cured doped polysilane film **103**, illustrated in FIG. **2**, is selectively oxidized to obtain the selectively oxidized doped polysilane film **104** exemplarily illustrated in FIG. **3**. The selectively oxidized doped polysilane film **104** comprises non-oxidized cured regions **104***a* and oxidized uncured regions **104***b*. The selectively oxidized doped polysilane film **104** is heated on the substrate wafer **101** for selectively diffusing the dopants from the selectively oxidized doped polysilane film **104** into the substrate wafer **101**. The diffusion of the dopants into the substrate wafer **101** selectively dopes the substrate wafer **101**.

FIG. **4** exemplarily illustrates diffusion of dopants into the substrate wafer **101** and formation of a crystallized polysilane film **105**. The selectively cured doped polysilane film **103**, exemplarily illustrated in FIG. **2**, is selectively oxidized to create the oxidized uncured regions **104***b* and the non-oxidized cured region **104***a* of the selectively oxidized doped polysilane film **104** as exemplarily illustrated in FIG. **3**. The oxidized uncured regions **104***b* are etched and removed from the surface **101***a* of the substrate wafer **101**. The substrate wafer **101** with the non-oxidized cured region **104***a* is then heated to diffuse the dopants into the substrate wafer **101** to create a local heavily diffused region **106**. Heating to diffusion temperatures converts the non-oxidized cured region **104***a* of the selectively oxidized doped polysilane film **104** into polycrystalline silicon **105**.

As exemplarily illustrated in FIG. **3**, the selectively cured doped polysilane film **103** acts as a diffusion source for diffusing the dopants into the substrate wafer **101**. In an embodiment, the doped polysilane film **102** is selectively deposited on the surface **101***a* of the substrate wafer **101** for creating patterns of the doped polysilane film **102** on the surface **101***a* of the substrate wafer **101**. The created patterns of the doped polysilane film **102** on the surface **101***a* of the substrate wafer **101** enable selective diffusion of the dopants into the substrate wafer **101** after curing and heating of the created patterns of the doped polysilane film **102**.

During heat treatment of the doped polysilane film **102**, for example, at temperatures above 600° C., the dopants from the doped polysilane film **102** diffuse out of the doped polysilane film **102** and dope the substrate wafer **101** below. FIG. **4** illustrates a structure for a solar cell where the non-oxidized cured region **104***a* from FIG. **3** is used as a local diffusion source to create a heavily diffused region **106** below the non-oxidized cured region **104***a*. On heat treatment of the selectively oxidized doped polysilane film **104** on the substrate wafer **101**, the dopants from the non-oxidized cured region **104***a* in FIG. **3** diffuse into the substrate wafer **101** to create the heavily diffused region **106** in the substrate wafer **101**, and the non-oxidized cured region **104***a* changes phase into a crystallized polysilane film **105**. The heavily diffused region **106** defines, for example, the heavily doped part of the emitter region of the solar cell. The diffusion process is, in general, a high thermal process, requiring long times and high temperatures. Depending on the type of dopants, temperatures around 900° C. are typically used to drive the diffusion process. The heat treating time is also dopant dependent, but is often longer than thirty minutes.

FIG. **5** exemplarily illustrates a substrate wafer **101** comprising a lightly diffused region **107** created by performing a second light diffusion step for making a continuous emitter. The doped polysilane film **102** as exemplarily illustrated in FIG. **1** is deposited on a silicon surface **101***a* of the substrate wafer **101** that has been previously doped by another method, for example, an ion implant, doped epitaxial growth, alternate surface diffusion from a phosphoric acid, phosphorus chloride oxide vapor, etc., to form a lightly diffused region **107** as exemplarily illustrated in FIG. **5**. In two embodiments, the silicon surface doping to form the lightly diffused region **107** is performed before or after the doped polysilane film **102** deposition. In an embodiment, heating the selectively oxidized doped polysilane film **104** on the substrate wafer **101** simultaneously creates the heavily diffused region **106** and the lightly diffused region **107** in the substrate wafer **101**. The diffusion process is performed at high temperature and generally crystallizes the doped polysilane film **102** to form the crystallized polysilane **105**. The doped polysilane film **102** crystallizes depending on the composition of the doped polysilane film **102** and the surface topography of the doped polysilane film **102**, and whether an interface layer is present. Typically, the surface **101***a* of the substrate wafer **101** has a thin native or chemical oxide present.

The diffusion process is performed in an inert atmosphere such as argon or nitrogen, or in an oxygen-rich environment. The diffusion process is performed, for example, in a belt furnace or a quartz tube furnace. The diffusion process can also be performed in a rapid thermal annealing system using short times but potentially higher temperatures.

FIG. **6** exemplarily illustrates use of a non-oxidized cured region **104***a* and oxidized uncured regions **104***b* of the selectively oxidized doped polysilane film **104** illustrated in FIG. **3**, as simultaneous diffusion sources. The doped polysilane film **102** is deposited on a surface **101***a* of a substrate wafer **101** as exemplarily illustrated in FIG. **1**. As exemplarily illustrated in FIG. **2**, the deposited doped polysilane film **102** is selectively cured on the surface **101***a* of the substrate wafer **101** to create a selectively cured doped polysilane film **103** comprising cured regions **103***a* and uncured regions **103***b*. The selectively cured doped polysilane film **103** is selectively oxidized to obtain the selectively oxidized doped polysilane film **104** comprising the non-oxidized cured region **104***a* and the oxidized uncured regions **104***b* as exemplarily illustrated in FIG. **3**. The selectively oxidized doped polysilane film **104** on the substrate wafer **101** is then heated, for example, in a tube furnace to diffuse the dopants from the non-oxidized cured region **104***a* and the oxidized uncured regions **104***b* into the substrate wafer **101** to create a heavily diffused region **106** and a lightly diffused region **107** as exemplarily illustrated in FIG. **6**. The heated non-oxidized cured region **104***a* and oxidized uncured regions **104***b* act as diffusion sources for diffusing the dopants into the substrate wafer **101** at different diffusion rates. The diffusion of the dopants into the substrate wafer **101** at different diffusion rates produces differentiated sheet resistances on the surface **101***a* of the substrate wafer **101**. The heavily diffused region **106** has a sheet resistance much lower than the lightly diffused region **107**. The diffusion process is performed at high temperature, and generally crystallizes the non-oxidized cured region **104***a* to form the crystallized polysilane film **105**.

If the curing of the doped polysilane film **102** is incomplete, the incompletely cured doped polysilane film is unstable. When the incompletely cured doped polysilane film is exposed to normal ambient environments, the incompletely cured doped polysilane film oxidizes slowly to become a silicon oxide film. The incompletely cured doped polysilane film can be oxidized by air or other oxygen environments or water to form the selectively oxidized doped polysilane film **104** comprising oxidized uncured regions **104***b*. The silicon oxide film can be removed by a silicon oxide etchant, for example, hydrofluoric acid, etc. The doped polysilane film **102**, amorphous silicon or the silicon oxides containing the dopants can then be used as diffusion sources for doping the substrate wafer **101**.

In an embodiment, the incompletely cured doped polysilane film need not be removed from the substrate wafer **101** before the high temperature diffusion process. The cured regions **103***a* and the uncured regions **103***b* as exemplarily illustrated in FIG. **2** of the selectively cured doped polysilane film **103** diffuse out dopants into the substrate wafer **101** at different rates resulting in different sheet resistances across the substrate wafer **101** to produce a selective emitter structure as exemplarily illustrated in FIG. **6**.

FIG. **7** exemplarily illustrates a substrate wafer **101** after simultaneous diffusion from a non-oxidized cured region **104***a* and oxidized uncured regions **104***b* of the selectively oxidized doped polysilane film **104**, with the oxidized uncured regions **104***b* removed after the diffusion process. The diffusion process performed at high temperature crystallizes the selectively oxidized doped polysilane film **104** to form the crystallized polysilane film **105**. The diffusion process creates the heavily diffused region **106** and the lightly diffused region **107**. The oxidized uncured regions **104***b* of the selectively oxidized doped polysilane film **104** are etched from the surface **101***a* of the substrate wafer **101**. Selectively oxidized doped polysilane films **104** are etched by a range of chemistries, as the selectively oxidized doped polysilane films **104** are not very dense. Wet chemicals that etch silicon and its oxides, for example, hydrofluoric acid, ammonium hydroxide, potassium hydroxide, etc. can be used to etch the polysilane films **102** and oxidized uncured regions **104***b* of the selectively oxidized doped polysilane films **104**. Most etches have high selectivity between the oxidized polysilane, non-oxidized polysilane, amorphous silicon, and crystalline silicon. If the oxidized uncured regions **104***b* of the selectively oxidized doped polysilane film **104** are removed after the diffusion process, the resulting structure is as exemplarily illustrated in FIG. **7**. The structure illustrated in FIG. **7** is identical to the structure illustrated in FIG. **5**, thus the same selective emitter structure can be achieved by two different process flows.

FIG. **8** exemplarily illustrates a solar cell structure manufactured using the method disclosed herein. Disclosed herein is a method for manufacturing a solar cell. A liquid precursor, for example, a polysilane liquid, is doped with dopants. The doped liquid polysilane precursor is deposited on a surface **101***a* of a substrate wafer **101** to create a doped polysilane film **102** on the surface **101***a* of the substrate wafer **101** as exemplarily illustrated in FIG. **1**. The doped polysilane film **102** is selectively cured on the surface **101***a* of the substrate wafer **101** to create cured regions **103***a* and uncured regions **103***b* of the selectively cured doped polysilane film **103** on the surface **101***a* of the substrate wafer **101** as exemplarily illustrated in FIG. **2**. The uncured regions **103***b* of the selectively cured doped polysilane film **103** are oxidized to create a selectively oxidized doped polysilane film **104** comprising oxidized uncured regions **104***b* as exemplarily illustrated in FIG. **3**. The oxidized uncured regions **104***b* of the selectively oxidized doped polysilane film **104** are etched from the surface **101***a* of the substrate wafer **101**. The substrate wafer **101** with the non-oxidized cured region **104***a* of the selectively oxidized doped polysilane film **104** is heated for diffusing the dopants into the substrate wafer **101** to create a heavily diffused region **106** in the substrate wafer **101**. After the diffusion process, a second diffusion step is performed to create a lightly diffused region **107**, for example, a lightly doped emitter region in the substrate wafer **101**. A silicon nitride (SiN) layer **108** is deposited on the substrate wafer **101**, covering all emitter regions and the doped polysilane film **102** which has crystallized to form the crystallized polysilane film **105**. The silicon nitride layer **108** is deposited, for example, by plasma-enhanced chemical vapor deposition. The silicon nitride layer **108** passivates the upper surface **101***a* of the substrate wafer **101** and acts as an anti-reflection coating. A metal contact **109**, for example, a silver paste is deposited on the deposited silicon nitride layer **108** on the surface **101***a* of the substrate wafer **101** by screen printing to create a layered structure **110**. On heating the layered structure **110**, the metal contact **109** penetrates the silicon nitride layer **108** to contact the crystallized polysilane film **105** or the heavily diffused region **106** to make the solar cell. The heavily diffused region **106** and the lightly diffused region **107** define one or more selective emitter regions on the surface **101***a* of the substrate wafer **101**. If there is a heavily diffused region **106**, for example, a selective emitter with heavy contact doping, the metal contact **109** is aligned to the heavily diffused region **106**. The structure produced using the polysilane film **102** as the heavy diffusion source is exemplarily illustrated in FIG. **8**.

Typically, solar cells use heavy doping under the metal contacts **109**. The doped polysilane film **102** formed from the liquid precursor acts as a diffusion source for diffusing the dopants into the substrate wafer **101**. The polysilane film **102** is cured to an air stable film by treatment with heat and/or light or both. Thus, the polysilane film **102** is patterned using, for example, ultraviolet light, a shadow mask process, or a locally focused laser, etc. The liquid precursor can also be deposited locally by a printing process, and then cured. After curing, the polysilane film **102** converts to a different form of polysilane or amorphous silicon. The incompletely cured doped polysilane film can be oxidized at room temperature in air, or can be oxidized at a higher temperature or in a moisture-rich or oxygen rich environment. The selectively oxidized doped polysilane film **104** is used for subsequent processing, or can be removed by etching. A high temperature process, for example, rapid thermal annealing (RTA) or furnace anneal is used to diffuse dopants from the doped polysilane film **102** into the substrate wafer **101**, creating a local heavily diffused region **106** in the substrate wafer **101**.

The polysilane film **102** as exemplarily illustrated in FIG. **1** can be deposited in selected areas of the substrate wafer **101** to produce diffusions in selected regions of the substrate wafer **101** during thermal processing. The light and heat sensitivity of the polysilane film **102** allow the polysilane film **102** to be readily patterned. The polysilane film **102** can be locally exposed to, for example, ultraviolet light similar to photolithography exposure process, an ultraviolet laser, or another laser which can heat the polysilane film **102** directly or by conductance from the heated adjacent layer.

Consider an example of manufacturing a silicon solar cell. A substrate wafer **101**, for example, a lightly doped p-type silicon wafer **101** is cleaned by immersion in a piranha solution. A piranha solution is, for example, about a one part hydrogen peroxide mixed with one part of sulfuric acid. The lightly doped p-type silicon wafer **101** is rinsed to remove chemical residues. The lightly doped p-type silicon wafer **101** is then hydrofluoric (HF) acid etched to remove the surface oxide. The lightly doped p-type silicon wafer **101** is rinsed again and then a metals removal clean is performed in a mixture or water, hydrogen peroxide, and hydrochloric acid with a mixture ratio of about 5:1:1 respectively. The clean lightly doped p-type silicon wafer **101** is then loaded into an inert ambient environment. A liquid precursor is prepared by a mixture of about two parts toluene and one part cyclopentasilane, with enough phosphorus tribromide solution added to give the liquid a silicon:phosphorus atomic ratio of about 50:1. This is an equivalent phosphorus doping level of approximately 1×10^{21} cm^{-3} in silicon. Using a K-bar coater the liquid precursor is coated onto the surface **101***a* of the lightly doped p-type silicon wafer **101** to form a doped polysilane film **102** with a thickness of about 250 nanometer. A shadow mask is then placed over the lightly doped p-type silicon wafer **101** and an ultraviolet-A/ultraviolet-B combined spectrum lamp light is directed onto the surface **101***a* of the lightly doped p-type silicon wafer **101**, curing local areas of the doped polysilane film **102** on the surface **101***a* of the lightly doped p-type silicon wafer **101**. Areas shaded by the mask are not cured. The ultra violet radiation dose is less than 1 Joule per cm square. The lightly doped p-type silicon wafer **101** can then be exposed to air at room temperature to oxidize the uncured region **103***b* of the lightly doped p-type silicon wafer **101**, which can then be removed by etching in approximately 4.9% hydrofluoric acid for about two minutes. The lightly doped p-type silicon wafer **101** is then loaded into a tube furnace with a pure nitrogen atmosphere at atmospheric pressure and heated to about 950° C. for about sixty minutes. The doped polysilane film **102** on the lightly doped p-type silicon wafer **101** crystallizes during the anneal process. Phosphorus dopants diffuse into the lightly doped p-type silicon wafer **101** under the doped polysilane film **102** to form a p-n junction about 0.8 microns below the doped polysilane film **102**.

In another manufacturing process, the surface **101***a* of a p-type substrate wafer **101** is textured by wet chemical etching. The substrate wafer **101** is then transferred to an inert ambient environment and the doped polysilane liquid precursor is deposited to form a doped polysilane film **102** on the substrate wafer **101** by screen printing. The screen print pattern is in the shape of fingers and bus bars, similar to the metal finger and bus bar pattern, but with slightly larger dimensions. The reason for making it larger is that in a later step, the metal contacts **109** must be printed onto the doped polysilane film **102** only, and not overlap onto the area on the substrate wafer **101** to be lightly doped. The doped polysilane film **102** on the substrate wafer **101** is then cured by ultraviolet light or by heating to more than 400° C. before being loaded into a furnace. The furnace is heated to a high temperature to diffuse dopants out of the doped polysilane film **102** into the substrate wafer **101**. A deposition of a phosphorus glass from POCl3 in the presence of oxygen is performed to create the diffusion source for the lightly diffused emitter. The substrate wafer **101** with phosphorus glass is then annealed in order to diffuse dopants out of the phosphorus glass and continue to diffuse dopants out of the polysilane film **102**. The substrate wafer **101** is then unloaded from the furnace, and the oxide is stripped off in hydrofluoric acid. A silicon nitride layer **108** is then deposited onto the heavily diffused region **106**, for example, an emitter region, of the substrate wafer **101**. A silver ink is then screen printed on top of the polysilane film **102** which is visible due to a different surface morphology compared to the remaining substrate wafer **101**. The ink is dried. Aluminum paste and silver paste soldering pads are screen printed onto the rear and dried. The metals are then heated in a belt furnace where the aluminum alloys with the rear surface to produce a heavily aluminum diffused region **106** or layer and the silver paste on the front punches through the silicon nitride layer **108** and contacts the heavily doped crystallized polysilane film **105** or the heavily diffused emitter region **106**.

Enumerated herein are examples for selectively diffusing dopants into the substrate wafer **101**.

Example 1

A doped liquid precursor is locally deposited on the substrate wafer **101** to create a local area doped polysilane film **102** on the surface **101***a*. The substrate wafer **101** with the doped polysilane film **102** is heated to diffuse the dopants into the substrate wafer **101** to create a heavily diffused region **106** in the substrate wafer **101** as exemplarily illustrated in FIGS. **4**-**8**. Subsequently, the substrate wafer **101** may be further processed to create a lightly diffused region **107** in the substrate wafer **101** as exemplarily illustrated in FIGS. **5**-**8**.

Example 2

A lightly diffused region **107** is created in the substrate wafer **101** by performing a light diffusion step. A doped liquid precursor is locally deposited on the surface **101***a* of the substrate wafer **101** to create a doped polysilane film **102** on the surface **101***a* of the substrate wafer **101** as exemplarily illustrated in FIG. **1**. The doped polysilane film **102** is heated to diffuse the dopants into the substrate wafer **101** to create a heavily diffused region **106** in the substrate wafer **101** as exemplarily illustrated in FIGS. **4-8**.

Example 3

A doped liquid precursor is deposited on the substrate wafer **101** to create a doped polysilane film **102** on the surface **101***a* of the substrate wafer **101** as exemplarily illustrated in FIG. **1**. The doped polysilane film **102** is selectively cured, for example, with ultraviolet light, to create a selectively cured doped polysilane film **103** comprising cured regions **103***a* and uncured regions **103***b* as exemplarily illustrated in FIG. **2**. The selectively cured doped polysilane film **103** is selectively oxidized to create a selectively oxidized doped polysilane film **104** comprising oxidized uncured regions **104***b* and a non-oxidized cured region **104***a* as exemplarily illustrated in FIG. **3**. The oxidized uncured regions **104***b* are removed. The non-oxidized cured region **104***a* of the selectively oxidized doped polysilane film **104** is heated to diffuse the dopants into the substrate wafer **101** to create a heavily diffused region **106** in the substrate wafer **101** as exemplarily illustrated in FIGS. **4-8**. Subsequently, the substrate wafer **101** may be further processed create a lightly diffused region **107** in the substrate wafer **101** as exemplarily illustrated in FIGS. **5-8**.

Example 4

A doped liquid precursor is deposited on the surface **101***a* of the substrate wafer **101** to create a doped polysilane film **102** on the surface **101***a* of the substrate wafer **101** as exemplarily illustrated in FIG. **1**. The doped polysilane film **102** is selectively cured, for example, with ultraviolet light, to create a selectively cured doped polysilane film **103** comprising cured regions **103***a* and uncured regions **103***b*, as exemplarily illustrated in FIG. **2**. The selectively cured doped polysilane film **103** is selectively oxidized to create a selectively oxidized doped polysilane film **104** comprising oxidized uncured regions **104***b* and a non-oxidized cured region **104***a* as exemplarily illustrated in FIG. **3**. The selectively oxidized doped polysilane film **104** is heated to simultaneously create a heavily diffused region **106** and a lightly diffused region **107** as exemplarily illustrated in FIGS. **5-8**. The oxidized uncured regions **104***b* of the selectively oxidized doped polysilane film **104** creates the lightly diffused region **107**, while the non-oxidized cured region **104***a* of the selectively oxidized doped polysilane film **104** creates the heavily diffused region **106**.

The foregoing examples have been provided merely for the purpose of explanation and are in no way to be construed as limiting of the present invention disclosed herein. While the invention has been described with reference to various embodiments, it is understood that the words, which have been used herein, are words of description and illustration, rather than words of limitation. Further, although the invention has been described herein with reference to particular means, materials and embodiments, the invention is not intended to be limited to the particulars disclosed herein; rather, the invention extends to all functionally equivalent structures, methods and uses, such as are within the scope of the appended claims. Those skilled in the art, having the benefit of the teachings of this specification, may effect numerous modifications thereto and changes may be made without departing from the scope and spirit of the invention in its aspects.

I claim:

1. A method for selectively diffusing dopants into a substrate wafer, the method comprising:

depositing a doped liquid precursor including dopants on a surface of the substrate wafer to create a doped film on the surface of the substrate wafer;

selectively curing the doped film to create cured regions and uncured regions of the doped film, wherein the selectively-cured doped film acts as a diffusion source for selectively diffusing the dopants into the substrate wafer; and

heating the doped film on the substrate wafer, wherein said heating of the doped film diffuses the dopants from the doped film into the substrate wafer.

2. The method of claim **1**, wherein said diffusion of the dopants from the doped film into the substrate wafer comprises simultaneous creation of heavily-diffused regions and lightly-diffused regions on the substrate wafer.

3. The method of claim **1**, further comprising creating a lightly-diffused region in the substrate wafer after said depositing the doped liquid precursor.

4. The method of claim **1**, wherein the doped liquid precursor is selectively deposited on the substrate wafer to create a plurality of patterns of the doped film, wherein the created patterns of the doped film enable selective diffusion of the dopants into the substrate wafer after said heating the doped film.

5. The method of claim **1**, wherein the doped film is selectively cured by patterned irradiation.

6. The method of claim **1**, further comprising heating the selectively-cured doped film to convert the selectively-cured doped film into silicon compounds.

7. The method of claim **1**, further comprising selectively oxidizing the selectively-cured doped film to create non-oxidized cured regions and oxidized uncured regions of the selectively-cured doped film.

8. The method of claim **1**, wherein the liquid precursor is selected from the group consisting of monomers, polymers, and oligomers of silicon and hydrogen.

9. The method of claim **1**, wherein the liquid precursor is one or more of a silane, an oligosilane, or a polysilane, with one or more of linear, branched, or particulate structures.

10. The method of claim **1**, wherein the dopants are one of positive-type impurities or negative-type impurities.

11. The method of claim **1**, wherein said depositing a doped liquid precursor is performed by one or more of ink-jet printing, screen printing, condensing, pneumatic spraying, ultrasonic spraying, electrospraying, spraying by liquid ejection from an orifice, spraying by direct injection of droplets of the doped liquid precursor impinging on the substrate wafer, spin coating, roller coating, bar coating, curtain coating, dip coating, or bar coating.

12. The method of claim **1**, further comprising doping a liquid precursor with dopants to form the doped liquid precursor.

13. The method of claim **1**, wherein the doped liquid precursor is photo-sensitive and heat-sensitive.

14. A method for selectively diffusing dopants into a substrate wafer, the method comprising:

depositing a doped liquid precursor including dopants on a surface of the substrate wafer to create a doped film on the surface of the substrate wafer;

selectively curing the doped film;

selectively oxidizing regions of the selectively-cured doped film; and

heating the selectively-oxidized doped film to selectively diffuse the dopants from the selectively-oxidized doped film into the substrate wafer.

15. A method for selectively diffusing dopants into a substrate wafer, the method comprising:

depositing a doped liquid precursor including dopants on a surface of the substrate wafer to create a doped film on the surface of the substrate wafer;

selectively curing the doped film to create cured regions and uncured regions of the doped film;

selectively oxidizing the uncured regions of the doped film to obtain oxidized uncured regions and non-oxidized cured regions of the doped film;

heating the non-oxidized cured regions and the oxidized uncured regions of the doped film; and

diffusing the dopants from the non-oxidized cured regions and the oxidized uncured regions of the doped film into the substrate wafer at different diffusion rates on said heating the non-oxidized cured regions and the oxidized uncured regions to produce differentiated sheet resistances on the surface of the substrate wafer.

16. The method of claim **15**, further comprising etching the oxidized uncured regions of the doped film from the surface of the substrate wafer.

17. A method for manufacturing a solar cell, the method comprising:

depositing a doped liquid precursor including dopants on a surface of a substrate wafer to create a doped film on the surface of the substrate wafer;

selectively curing the doped film to create cured regions and uncured regions of the doped film;

oxidizing the uncured regions of the doped film and etching the oxidized uncured regions of the doped film from the surface of the substrate wafer;

heating the cured regions of the doped film, wherein said heating of the cured regions of the doped film diffuses the dopants into the substrate wafer to create a heavily-diffused region in the substrate wafer;

creating a lightly-diffused region in the substrate wafer;

depositing a passivation layer on the heated cured regions of the doped film;

depositing a metal contact on the deposited passivation layer to create a layered structure; and

heating the layered structure to allow the metal contact to penetrate the passivation layer and contact the heavily-diffused region.

18. The method of claim **17**, wherein the passivation layer comprises silicon nitride.

19. The method of claim **17**, wherein the lightly-diffused region is formed after creation of the heavily-diffused region.

20. The method of claim **17**, wherein said creating a lightly-diffused region in the substrate wafer is performed after creating the heavily-diffused region in the substrate wafer.

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